ON THE THERMAL CONDUCTIVITY OF VULCANITE.

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LAST year Dr. R. W. Willson and I published in these Proceedings an account of some determinations of the thermal conductivities of different kinds of marble, made by the so called "Wall Method."

A relatively thin, square, plane-faced slab of the material to be examined, enclosed between two other slabs of the same material, formed a rectangular parallelopiped or prism, which was clamped, and left for many hours, between the steam chest, A, and the ice box, Z, of the apparatus * represented by Figure 1. The final temperatures at the

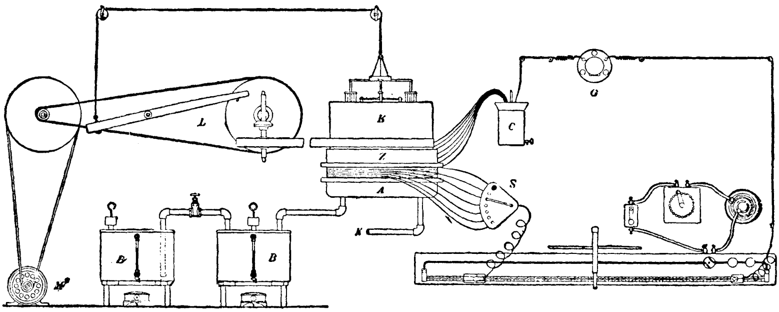

FIGURE 1.

centres of the faces of the slab to be tested were determined by the aid of thermal elements, and the flux of heat through a definite central portion of the colder base of the prism was measured. Figure 2 represents the revolving ice holder, which was kept in motion by the motor, M; and Figure 3 shows the ice pot used in measuring the heat flux.

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* This was partly constructed with the help of an appropriation from the Rumford Fund of the Academy.

The present paper describes a series of experiments on the thermal conductivities of different specimens of hard rubber,* or "vulcanite," made by the method which we described at length last year.

I had at my disposal fourteen different pieces of hard rubber thick enough to be used conveniently in the apparatus, and much of this was in sheets about 120 cm. by 50 cm. So much of it as was bought for the purposes of this investigation came from three well known makers. Besides this new rubber, however, there were a number of pieces from

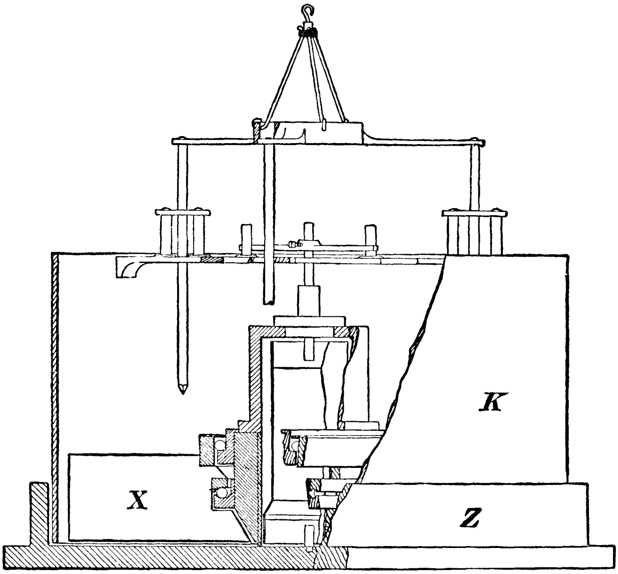

FIGURE 2.

unknown sources, which had been lying in the laboratory for indefinite periods. The specific gravities of the different specimens examined differed slightly from each other, but by not nearly so much as one per cent in the extreme cases. The specific gravity of the rubber used as a standard is about 1.202, and its average specific heat between 25° C. and 100° C. is 0.339. The specific heat of sheet rubber usually increases with the temperature, as may be inferred from the subjoined table, in

* Stefan, Sitzungsberichte der Wiener Akademie der Wissenschaften, 1876; Lees, Philosophical Transactions, 1893.

the second column of which is given the number of calories required to raise one gram of a certain kind of thin sheet rubber from 25° C. to the temperatures given in the first column. The third column gives the average specific heat between 25° C. and these temperatures.

Temperatures.	Calories.	Average Specific Heat.
35°	3.17	0.317
45°	6.46	0.323
55°	9.91	0.330
65°	13.47	0.337
75°	17.20	0.345
85°	21.22	0.354
95°	25.48	0.364
100°	27.90	0.372

The average specific heat of another specimen of thin hard rubber between 25° C. and 100° C. was 0.370.

Since hard rubber is an extremely poor conductor of heat, a long time was required in the case of any prism for the final state to be reached approximately. After about seven or eight hours, if the temperatures of the hot and cold boxes were kept quite constant, the temperatures at all points on the axis could generally be assumed to be within one twentieth of a degree of their final values; and, in view of the variable composition of what is called "hard rubber," "ebonite," or "vulcanite" in the market, and of the extreme difficulty of keeping the temperature of the hot box constant within less than one tenth of a degree for any great number of hours, it did not seem desirable to extend the experiments further. In what follows, the conductivity is given in every case to three decimal figures, but it is evident that the third figure is not quite determined.

Experiment (*a*). — A compound slab, made up of two plates (A and B), of a certain kind of hard rubber which I chose as a standard, with their thermal elements, was placed between two other pieces of hard rubber to form a prism. Each plate was about 60 cm. long by 50 cm. broad. The average thickness of A was 1.270 cm., and that of B 1.260 cm. In the final state the thermal elements on the warmer side of A, between A and B, and on the cooler side of B, indicated 74°.9, 45°.2, and 15°.7 respectively. The rate of melting of the ice in the box was 102 grams in almost exactly 8,760 seconds. Assuming the area of the bottom of the ice pot to be 126.7 square centimeters, and the latent heat

of melting ice to be 79.25, this corresponds to a conductivity for *each slab* of 0.000311.

Experiment (*b*). — Plate A with two thermal elements, enclosed by two other sheets of hard rubber, was made into a prism with three plates of glass. In the final state the temperatures of the elements on the faces of A were 60°.1 and 24°.9 respectively. In 11,220 seconds 154.8 grams of ice were melted. This again corresponds to a conductivity between 60° and 25° of 0.000311.

Two other experiments in which the final gradients on the axes of prisms built up of disks about 20 cm. in diameter made of this rubber were determined, failed to show any sensible variation of the conductivity with the temperature between 65° and 16°.

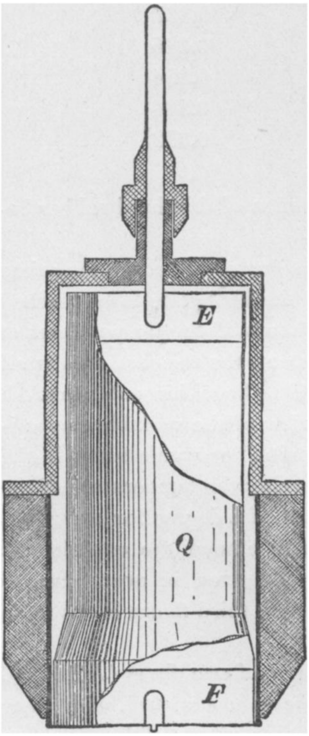

FIGURE 3.

Experiment (*c*). — A compound slab made of A and a plate, C, of the same dimensions as A, but purporting to come from another maker, with their thermal elements and "guard plates" of rubber, were used to form a prism for the large apparatus. In the final state the indications of the elements on the warm side of A, between A and C, and on the cool side of C, were respectively 69°.8, 41°.1, and 13°.1, so that the conductivity of C between 41° and 13° appears to be 0.000319.

After this a number of disks 20 cm. in diameter, which seemed alike in their physical properties, were cut from the standard rubber and used with other disks to form prisms for the smaller apparatus.

Experiments (*d*) *to* (*o*). — By the aid of these standard disks the conductivities of twelve other specimens were easily obtained. I give in the next table the results, not in the order in which the experiments were performed, but, for convenience, in the order of the conductivities of the specimens.

Specimens.	Thickness in Centimeters.	Temperature Limits.	Conductivity.
D	1.584	44°.4 and 16°.5	0.000317
E	1.265	40°.1 " 15°.8	0.000313
F	1.297	40°.1 " 14°.9	0.000309
G	1.254	40°.5 " 16°.1	0.000307
H	0.979	37°.0 " 16°.4	0.000305
I	0.499	50°.0 " 23°.9	0.000282
J	1.003	37°.0 " 12°.1	0.000256
K	0.945	36°.1 " 12°.6	0.000254
L	0.797	35°.2 " 12°.5	0.000237
M	0.643	33°.1 " 13°.2	0.000217
N	0.644	32°.8 " 12°.2	0.000214
O	0.498	30°.6 " 12°.8	0.000200

In view of the suspicious decrease of the thermal conductivity with the thickness of the prism experimented on, it is well to say that some manufacturers apparently use rubbers of different compositions for thick and for thin plates. Much cheap thin rubber is to be had in the market, and the specific electrical resistance of some of this is so low as to make the material useless for insulating purposes. Of the specimens mentioned in the table, *G* and H are pieces of expensive rubber made especially for use in induction coils of high grade. K, which is nearly of the same thickness as H, is an excellent rubber of high electrical resistance, but is not quite equal in this respect to H, which has a very different thermal conductivity. Extended experimentation seemed to show that the indications of the thermal elements might be trusted whether the plates were thick or thin. A redetermination of the conductivities of N and O with different arrangements of the prisms gave 0.000215 and 0.000199 respectively. When a disk of the standard rubber was turned down thin, and its specific conductivity redetermined, it was found to be almost the same as before; but when disks F and I were made slightly thinner by turning off the polished surface on each side, the conductivity of the thinner disks was increased by five per cent and three per cent respectively. This seems to show that in the cases of some sheets of hard rubber the thermal conductivity of the skin near the polished surfaces is somewhat less than that of the mass of the material in the sheet. This difference, however, is too slight to account for the differences of conductivity shown by the table. It is well to emphasize the fact that the specific heat between 25° C. and 100° C. of the standard rubber is less (0.339) than that of the thinnest sheet rubber (0.372) that I have experimented upon.

Stefan found for the thermal conductivity of a certain sheet of rubber, 0.787 cm. thick, the value 0.00026; this rubber had a somewhat greater density (1.22) and a much lower specific heat (0.23) than any of my specimens, so that the ratio of the conductivity to the specific heat per unit volume was somewhat greater. Experimenting upon a thin disk of "ebonite," 1.93 cm. in diameter and 0.0414 cm. thick, Lees determined the conductivity to be 0.000403.

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